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**STATUS OF CURRENT DEVELOPMENT ACTIVITY
RELATED TO STOL PROPULSION NOISE REDUCTION**

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ABSTRACT

The noise goal of 95 PNdB for STOL aircraft imposes severe technology demands on propulsion systems. Effects of this goal on the design of the propulsion system are reviewed. Results from recent development programs associated with STOL noise reduction, such as high bypass fan tests, 25 PNdB acoustic suppression tests, sonic inlets, and powered lift system noise tests, are presented. Integrated propulsion system designs for the blown flap and augmentor wing powered lift systems capable of meeting the noise goal are shown and the performance, installation, and economic penalties assessed.

INTRODUCTION

A viable STOL system will, by its nature, provide service out of heavily congested areas. As a consequence, the environmental specifications that will be imposed on these systems will be very severe. Extremely quiet and pollution-free operation will be demanded. Noise goals for these systems will require the initiation of major development efforts if they are to be satisfied.

The affect of the noise goal on the design of the propulsion system is such that parameters previously used to define the component and installation design are now secondary to the noise requirement. Large reductions in jet, machinery, and powered lift noise are required if the noise goal is to be achieved.

New development programs have been initiated to obtain the technology required for the design of propulsive lift propulsion systems. This effort has concentrated largely on the blown flap and augmentor wing powered lift concepts, and has endeavored to provide solutions at the component, subsystem, and system level.

Very high by-pass fan technology has been pursued using small scale and large scale models. The aerodynamic and acoustic performance of these fans has been evaluated at a component level, and at a subsystem level, while subjected to the high angle of attack flight conditions which are typical of STOL operation.

Extensive test programs were initiated to evaluate the effectiveness of passive and active acoustic suppression techniques on component noise for STOL applications. Results were obtained from full-scale tests using a TF-34 engine for a test bed and from scale models for sonic inlet development.

In addition to the component development activity, a significant technology base has been established on powered lift system noise. The influence of this noise source on the performance, installation design, and economic performance of the propulsion systems has been evaluated during comprehensive design study programs. Results of the studies and the development activities are presented in detail in this paper.

EFFECT OF THE STOL NOISE GOAL

The generally discussed 500-foot sideline noise goal of 95 EPNdB for STOL aircraft imposes great demands and limitations on the design of propulsion systems for powered lift aircraft. The severity of this noise goal can readily be appreciated by referring to figure 1. This figure compares the present FAR part 36 noise requirement for conventional takeoff and landing (CTOL) aircraft, extrapolated to a 500-foot sideline measuring point, with the STOL goal, and for comparative purposes with the CTOL NASA Quiet Engine A program results (1)*. Note that the STOL goal is approximately 30 PNdB lower than existing regulations and 13 PNdB less than was achieved with the Quiet Engine A. The effort required to achieve this goal is made more difficult when one considers that powered lift systems generate an additional noise source as compared to CTOL systems. The externally blown flap systems (fig. 2) have flap impingement and scrubbing noise which results from the flow of engine airflow over and against wing and flap surfaces. The augmentor wing lift system (fig. 3) has augmentor noise from the discharge of a high pressure jet into the flap system. Additionally, when comparing

*Numbers in parentheses designate References at end of paper.

STOL noise to CTOL noise, one finds that there is an approximate 3 dB penalty associated with STOL systems due to the fact that the thrust-to-weight ratios of STOL systems are roughly twice those of CTOL systems.

It is both the magnitude of the noise goal and the type of source noise that affects the design philosophy for powered lift propulsion systems. Let us first examine the affects of the noise goal on jet noise. Figure 4 illustrates that, if a noise level of 95 PNdB is to be achieved, a corresponding maximum velocity less than 850 feet per second is required for both the fan flow and core flow. Note that this velocity corresponds to very high by-pass fan engine configurations. For the blown flap powered lift systems, it has been found that still further reductions of exhaust velocities are required in order to reduce the powered lift source noise, e.g., flap impingement and wing scrubbing, to the desired level. STOL propulsion system design is influenced very strongly by both the noise goal and the noise source. The influence of the goal is such that optimization of parameters such as thrust/weight, and cruise thrust become secondary parameters, and are optimized only after the primary parameters, fan pressure ratio and core velocity, set by the noise goal, are satisfied. This is a departure from designing propulsion systems for optimized aerodynamic and economic performance at the onset.

A description of the problems associated with achieving the STOL noise goal is found in the review that follows of recent development activity in the fields of low pressure-ratio fans, acoustic suppression, powered lift noise, and propulsion system analysis.

LOW PRESSURE-RATIO FAN DEVELOPMENT

Two of the leading powered lift concepts (fig. 2) utilize an externally blown flap configuration to develop high lift coefficients. As mentioned previously, the degree of source noise suppression that can be obtained with these lift systems is dependent on the exhaust velocities of the flow over the wing and flap surfaces. The low velocities required necessitate the use of low pressure-ratio, high by-pass fan engine designs. The highest by-pass fan engines in commercial use today are found in the new wide-body transports. These engines have approximately a 6-to-1 by-pass ratio. Recent studies have shown that by-pass flows of 8-12 to 1 and 15-18 to 1 are best suited for the over-the-

wing and under-the-wing powered lift concept, respectively. The technology for the fans of these engines is new and just recently has begun to yield results.

Large Scale Fan Development

For STOL installations, it is desired that high by-pass low pressure-ratio fans produce a minimum of machinery noise along with low velocities and jet discharge noise. Two design concepts are presently being evaluated which differ primarily in blade number, solidity, and construction. Table I summarizes the salient differences between two six-foot fan designs which were evaluated at the Lewis Research Center. The QF-9 configuration is a Hamilton-Standard Q-fan design which was evaluated also in a 20-inch aerodynamic model. This design (fig. 5) uses a spar-shell blade construction technique, typical of propellers, with a large blade chord and a minimum of rotor and stator blades which keeps the blade passing frequency below the high annoying frequency band of 2 to 6000 hertz. The blades are heavily loaded and have a tip solidity less than one. Encouraging acoustic results had previously been obtained with a smaller-scale, lower-pressure-ratio fan of the same design philosophy (2).

The QF-6 fan (fig. 6) is a fixed-pitch, more conventional blade design which utilized a slightly higher solidity and tip velocity, lower aerodynamic loading, and twice the rotor-stator separation in rotor chord lengths as the QF-9 fan design. A comparison of the 1/3-octave sound-pressure level spectra of both fans is shown in figure 7. Both fans were run at design blade angles and speed. The third octave spectra is typical of that expected from subsonic single-stage fan operation. The blade passage frequency and its harmonic are shown for both fans. Note that the QF-9 blade passage frequency is well below the high annoyance frequency band.

The acoustic performance of both fans, at a 500-foot sideline, is also shown in figure 8 for unsuppressed fan noise scaled to a 90 000-pound thrust level. This figure shows the acoustic performance of two-stage and single-stage fans over a wide range of pressure ratios. The data points for the QF-6 and QF-9 fans are plotted in the band for single-stage low speed fans. The "fixed" pitch data point is for the QF-6 fan, and the data point labeled "variable" is for the QF-9 fan.

System Tests

Along with the smaller scale aerodynamic models and 6-foot acoustic models, a full-scale Q-fan matched to a T-55 engine has been built and is being evaluated in a systems test by Hamilton-Standard. This fan is of a 55-inch diameter, has a design pressure ratio of 1.18, a tip solidity of 0.67, 13 rotor blades, 7 stator blades, a blade passing frequency of 730 cps, maximum power blade angle of 51.8° , and a tip speed of 810 feet per second. A test program is being sponsored by NASA to evaluate the acoustic and aerodynamic performance of the fan and to evaluate the compatibility with the drive engine. The test configuration has manually settable blade angles which permit the complete excursion of pitch settings to be explored, including reverse thrust.

Figure 9 shows that the design blade angle setting of 51.8° produced optimum acoustic results for any given value of thrust. It should be noted that the variable fan permits some trade-off to be made of noise for a given thrust setting. At the higher power settings, approximately 2.5 dB can be achieved by resetting blade angle and fan speed, while at lower powers (2800 lb thrust) as much as 6 dB reduction can be realized. This reduction does, however, require a further trade-off to be made which is of thrust response time. One of the features of the variable pitch fan is its ability to reduce thrust response time. This is accomplished by keeping the fan speed at a high level with low values of blade angle, hence thrust, and then increasing blade angle to initiate the thrust response. This technique converts the angular momentum of the fan spool into thrust while the engine core accelerates to the desired level. It can be seen from the line of maximum speed plotted in the figure that if rapid thrust response is to be obtained by maintaining a constant fan speed and changing blade angles, nonoptimum acoustic performance would result. For example, if the 2800-pound thrust level is considered to be an approach power setting, it is seen that, by maintaining maximum speed for improved thrust response, a penalty of 6 dB must be taken from the optimum acoustic performance. A flight application of the Q-fan will require a thorough evaluation of the trade-offs obtainable, over the flight envelope, between performance, thrust response and system noise.

Additional testing is planned for this fan-engine system, in particular to evaluate performance and noise in the reverse thrust regime both through the feather and flat pitch settings.

Installation Effects

STOL takeoff and landing operation results in an air flow entrance to the engine inlet which is at very high angle of attack. In order to evaluate the effects of angle of attack on the aerodynamic and acoustic performance of low pressure ratio fans, tests (3) were conducted at the Lewis Research Center using a powered engine simulator driving a 20-inch 1.15 PR fan. Two different inlet configurations were evaluated. Figure 10 shows the results obtained with an inlet which had a contraction ratio, highlight area (A_{Hi}) to throat area ratio (A_t), of 1.26. The plots show the increase in sound pressure level that was obtained as a function of angle of attack. From figures 10 and 11, it is seen that there is very close correlation between the rapid increase in aerodynamic distortion that began at 30° and the increase in sound pressure level. Similar results were obtained with an inlet which had a contraction ratio of 1.35. With this inlet, the build-up in aerodynamic distortion and noise level began after an angle of attack of 40° was reached. These tests show that the total propulsion system design must account for the effects of flight variations in order to satisfy both the acoustic and aerodynamic design requirements.

ACOUSTIC SUPPRESSION DEVELOPMENT

From the previous discussion it can be seen that a substantial amount of acoustic suppression will be required, even with the quietest fan technology available, if the STOL noise goal is to be realized. From figure 8 it can be deduced that even at the low fan pressure ratios of 1.25, representative of the blown flap powered lift system, approximately 15 PNdB of fan suppression is required for the four engine case shown to achieve a 95 PNdB goal. The suppression per engine calculates to be 18 PNdB. An augmentor wing system having a fan with a pressure ratio of 3.0, will require greater than 30 dB of suppression. Results from some of the recent development activity which endeavored to reach greater than 15 PNdB of suppression per engine are presented in the following section.

TF-34 Acoustic Nacelle Tests

Previous engine-acoustic nacelle programs, that have been conducted to evaluate the acoustic effectiveness and aerodynamic performance of acoustic treatment, had as target goals a maximum fan noise suppression of approximately 15 PNdB. A development effort was initiated in 1971 to extend the existing data base by providing design configurations capable of providing the 25 PNdB reductions which might be required for STOL systems. A TF-34 engine was selected as a test bed because its high by-pass ratio (6 to 1) provided a relatively low jet exhaust noise which could be lowered still further by exhaust area modifications.

One of the objectives of the TF-34 acoustic nacelle program was to demonstrate fan noise reduction of 26 PNdB with bulk absorber treatment and 22 PNdB with single degree of freedom (SDOF) honeycomb. Figure 12 is a schematic of the engine nacelle test configurations. The nacelle was designed with a minimum cost approach. Note, for example, that the splitters do not conform to flow lines but are straight sections readily fabricated. An adjustable position three-ring inlet splitter configuration was fabricated to permit the evaluation of the affects of splitter location to the fan face. The inlet splitters were aluminum honeycomb. Two aft fan splitters designs were fabricated. One was a honeycomb, SDOF configuration, the other was a bulk absorber Scottfelt material. Core treatment consisted of a high temperature bulk absorber (Cerafelt) of two different thicknesses. The results which will be presented are based on the honeycomb SDOF inlet splitters, Scottfelt aft splitters and Cerafelt exhaust treatment.

Results obtained from the test program to date indicate that good correlation exists between the predicted analytical design results and the actual. A 50-hertz narrowband comparison of the TF-34 noise spectrum, at maximum power, suppressed and unsuppressed, is shown in figure 13. The suppression was tuned to the blade passing frequency which is 3150 hertz. Even though the core jet noise and fan jet noise were reduced as far as possible, by increasing the jet exit areas within the operational capability of the engine, they became the noise floor for the system at maximum power. As a consequence, acoustical techniques such as directional array microphones were utilized to measure fan noise and predict the amount of fan noise suppression that was obtained but which was masked by the jet noise floor limit. Some of the more

important conclusions reached from this program are as follows:

1. Reductions of 21-24 PNdB in maximum 500-foot sideline total system noise have been achieved (when measured on an equal fan pressure ratio basis) for the separate flow treated nacelle.

2. Fan pure tone SPL reductions of 25-35 dB were measured in the far-field when reduced on a 1/3-octave basis. When the comparisons were made on the basis of 50 hertz narrowband data, the measurable farfield tone reductions were 43-47 dB.

3. Examination of the farfield 50 hertz narrowband spectra indicates that at the maximum speed point the fan pure tones have all been virtually eliminated by the treatment.

Performance losses attributed to the fan and core acoustic treatment were measured. The pressure losses at maximum power were as follows:

Inlet, 1.5 percent

Fan duct, 7.2 percent

Core suppression, 3.2 percent

These pressure losses resulted in a total thrust loss of 14 percent. Calculations made for splitter designs that have been optimized for aerodynamic performance show that the total takeoff thrust loss at maximum power should be approximately 8.0 percent.

Sonic Inlets

In addition to the passive technique of using acoustic noise, an active device, such as the choked or sonic inlet, can be used which also minimizes the inlet aerodynamic performance losses. This device utilizes the principle that sound waves are attenuated while moving upstream in a high Mach number flow stream. At a choked or Mach 1 condition, the sound waves, theoretically, will be unable to proceed forward of the sonic plane, thus providing complete attenuation of the sound wave. The sonic inlet is well-suited for the augmentor wing powered lift system which requires a propulsion system with a fan pressure ratio of approximately 2.5 to 3.0. To achieve this pressure ratio, a multi-stage fan is required, which as seen from figure 8 results in a very high fan noise level. Between 25 to 30 dB of inlet fan noise suppression is required to achieve the STOL noise goal.

A new development effort was initiated in 1972 to review the results of previous activity in this field (from 1960) and to select the most promising concepts for further refinement and optimization. This effort was conducted by The Boeing Company in an anechoic chamber with a 12-inch, 1.5 PR fan. The screening process narrowed the final test configurations to a translating centerbody concept and a multipassage inlet using movable radial vanes. An adjunct program was conducted at the Lewis Research Center for the purpose of evaluating the affects of velocity and angle of attack on both the acoustic and aerodynamic performance of sonic inlets.

The effectiveness of the sonic inlet is shown in figure 14 which shows the large reductions in discrete and multiple pure tones that are obtained with these devices (4). The aerodynamic performance, for an approach flight condition, is shown in figure 15 for three different inlet types (4). These results indicate that high noise reduction with tolerable aerodynamic loss can be achieved with sonic inlets. References 4 to 7 present, in detail, the results of the recent developments in sonic inlets.

POWERED LIFT NOISE

The noise that is generated by every powered lift system, and which is peculiar to each system, has proven to be one of the most difficult noise sources to control and one which has major affect on the design of the propulsion system for the applications. During the past 2 years, extensive development activity has been initiated to provide insight of the noise source and design approaches and solutions for the reduction of the noise source. Most of the development effort has been applied to the under-the-wing blown flap noise area mainly because of the recent interest that had been in evidence for this lift concept. Substantial effort has also been applied to the over-the-wing blown flap and the augmentor wing lift systems.

Blown Flap Noise

Noise generated by both the under-the-wing and over-the-wing blowing systems consists of the noise of engine itself, machinery and jet mixing, plus wing scrubbing noise, and flap leading edge and trailing edge noise. The over-the-wing installation has an additional noise source if a deflector is used to

position the jet so that it attaches to the wing surface. However, the over-the-wing installation provides a major acoustic benefit in that the wing-flap system shields a substantial amount of the noise in flight. Research and development activity has centered largely around small-scale cold gas tests of various exhaust nozzle and wing sections plus two full-scale engine test programs investigating both over-the-wing and under-the-wing powered lift noise. The large-scale tests consisted of a CF700 engine-F111 wing and flap test (8) and a TF-34 engine test with a triple slotted wing section.

Plotted in figure 16 are the results from large-scale cold gas tests (9) which compare the noise patterns for both the upper surface and lower surface blowing powered lift systems. The noise directionality and the shielding of the over-the-wing installation are evident. Results of all testing to date show that flap noise can be controlled mainly by reducing the impingement velocity of the fan and core airstream. Results from cold gas model tests, shown in figure 17, indicate that only relative low exhaust velocities will provide a noise level acceptable for STOL systems. These low velocities are not typical of today's fan engines and can only be provided with fans in the 1.25 pressure-ratio range. Lower flap impingement velocities can also be obtained with special exhaust nozzles (mixer decayer) which break up the fan stream into smaller jets, thus producing more rapid mixing and large velocity decay over a shorter distance.

The TF-34 engine and acoustic nacelle were evaluated with various nozzle combinations and decayers with a wing section for both the under-the-wing and over-the-wing configurations. Results of this program are summarized in figures 19 and 20. Schematics of the nozzle configuration tested are shown in figure 18. For the takeoff flap configuration, it is seen (fig. 19) that the fly-over suppressed engine noise, with no wing, increased approximately 12 PNdB when the fan and core flow from a separate flow co-annular nozzle impinged on the flaps. A 12-lobe internal and external mixer-decayer was installed to reduce the impingement velocity. It was found, however, that although the velocity decay achieved was more than required, 8 PNdB of noise was generated by the mixer-decayer (fig. 20). Tests of the mixer-decayer with the wing and flap system produced a noise level increase of 13 PNdB over that from the suppressed engine without wing. A redesign of the decayer proved effective in reducing mixing noise. To reduce the mixing noise still further, an acoustic shroud was placed over the decayer. With this final configuration, it was

found possible to limit the under-the-wing noise to an increase of 5 PNdB over that of the suppressed engine without a wing. All the above results (fig. 19) are shown plotted for a fly-over noise condition. Measurements were also made to establish the sideline noise with the various test configurations. This data (fig. 20) showed an average sideline noise reduction of 5 PNdB from that of the fly-over noise. This reduction was due to directionality differences in the noise patterns from the fly-over to the sideline measuring points. It was found that the sideline noise for the best under-the-wing exhaust configuration was equal to that of the suppressed engine without a wing.

One test was conducted to establish a data point for the noise of an over-the-wing lift system using a TF-34 engine. The quietest suppressed engine exhaust configuration was used, which was an internal core mixer discharging into a conical fan exhaust duct. A deflector plate was added to the exhaust exit to attach the flow to the wing. A penalty of 7 PNdB resulted from the use of the deflector plate (fig. 20). Figure 19 shows that the over-the-wing fly-over noise is quieter than that obtained with the best under-the-wing exhaust system. The sideline noise was found to be only 1 PNdB higher than that of the suppressed engine by itself.

Augmentor Wing Noise

Noise from the augmentor wing powered lift system is that due to the discharge of a very high velocity jet through the wing slot. The nozzle pressure ratio used for current augmentor development activity is between a 2.5 and 3.0 value. This results in a noisy supersonic jet discharge.

Recent development activity in augmentor wing noise has largely been conducted by The Boeing Company under NASA, Ames Research Center, sponsorship (10). This work has been done with approximately 1/6th scale models. Results of this activity are summarized in figure 21. A high-aspect-ratio slot nozzle discharging 300° F air, at a nozzle pressure ratio of 2.6, produces a peak noise level of 116 PNdB at a 500-foot sideline. To reduce the total system noise to the 95 PNdB level, greater than 21 PNdB of suppression of this source noise is required. The process used to reduce the slot noise consisted of first breaking up the slot nozzle to increase the source frequency; a screech shield was added to the nozzles to eliminate screech; and finally, the wing was acoustically treated and a baffle added to the secondary air gap.

The incremental noise reductions which correspond to the various modifications are shown in the plot. Large scale testing of optimized scale augmentor configurations is in the planning stage.

STOL PROPULSION SYSTEM STUDY RESULTS

In parallel with the STOL component development activities, a comprehensive study program was initiated in 1972 which was composed of a propulsion element and a total system element. Two engine manufacturers, General Electric and Allison Division of General Motors, with associated subcontractors, evaluated propulsion systems for the blown flap and augmentor wing powered lift systems. McDonnell-Douglas and Lockheed Aircraft performed airframe and system evaluations using the propulsion systems generated by the engine manufacturers. These studies began as broad parametric evaluations and were refined to eventually yield optimized total STOL systems.

Propulsion System Configurations

Representative optimized propulsion systems for the three powered lift systems studied are shown in figures 22 to 24.

In order to achieve the 95 PNdB sideline noise goal, it was found the fan pressure ratio for the under-the-wing engine optimized at 1.25 and the over-the-wing engine optimized at 1.35. The augmentor wing fan pressure ratio optimized at 3.0 largely because of installation trade-offs. Presented in the figures are comparison performance values obtained from the two engine contractors. Differences are due largely to the fact that each engine manufacturer used a different high-pressure core.

A more detailed comparison of the blown flap engines with a modern high-bypass engine is shown in table II. Note that the fan diameter of the under-the-wing powered lift engine is nearly the same as the CTOL engine though it has but 0.6 of the thrust value. The low-pressure-ratio engines require a two-position exhaust nozzle to achieve optimized cruise performance. Thrust-to-weight ratios at takeoff are good; but, because of its high thrust lapse rate, the 1.25 PR engine provides the lowest ratio at altitude.

Acoustic and Economic Performance

A 500-foot sideline measuring point alone does not permit a sufficient comparison to be made of the noise associated with various powered lift concepts. Directionality affects and the magnitude of installed thrust have heavy influence on the land area affected by the powered lift aircraft. Plotted in figure 25 are the noise footprints for three powered lift concepts. All were designed to meet a 95 EPNdB 500-foot sideline noise after lift-off. The augmentor wing is seen to have the smallest approach footprint and the largest takeoff and total footprint. This is because this lift concept requires less installed thrust to meet the field length requirement. It does, as a consequence, climb out at roughly half the climb angle of the blown flap system. Noise shielding obtained by the over-the-wing installation provides for a sizeable reduction in the 90 EPNdB footprint.

Economic penalties associated with the STOL noise goal are depicted in figure 26 for the blown flap powered lift systems. For the under-the-wing system, a penalty greater than 2 percent in direct operating cost (D.O.C.) is paid for each EPNdB of suppression from 95 to 100 EPNdB for a 150-passenger aircraft. The advantage of the variable pitch fan over the fixed pitch fan is evident at the low noise values. Even higher penalties for noise reduction are paid with the over-the-wing installation - approximately 3 percent D.O.C. per EPNdB.

Similar sensitivity in direct operating cost is seen to exist for the trade-off of field length for a powered lift system which has been designed for a 95 EPNdB sideline goal. Figure 27 shows that an 8 percent decrease in D.O.C. can be obtained by increasing the design field length to 3000 feet. A reduction of 1.5 EPNdB is also achieved. A larger reduction in D.O.C., for a 3000-foot field length, can be obtained, with a constant noise goal, if the fan pressure is changed to a value of 1.30.

CONCLUSIONS

It has been shown that a STOL noise goal of 95 PNdB at a 500-foot sideline has severe impact on the design of the propulsion system for the three powered lift systems discussed.

Results obtained from recent tests conducted on high-by-pass fans show

that the acoustic performance of these fans can be predicted. The low-pressure ratio, variable-pitch fan has been shown to have noise and economic advantages when compared to the fixed pitch fan with a thrust reverser.

Results from wind tunnel tests indicate that the inlet installation design for STOL propulsion systems must also consider the affects of distortion on system noise as well as on aerodynamic performance.

It was shown that acoustic suppression can yield large reductions in fan noise, greater than 25 PNdB, but that the performance penalties associated with the reductions require further development activity to minimize these losses. The performance of the sonic inlet, in small model tests, shows promising returns in noise suppression with acceptable performance losses.

Powered lift noise has been evaluated both in small scale and full scale. It has been shown, for the blown-flap powered-lift system, that the noise generated by the lift mechanism is largely a function of the exhaust velocity of the engine, and that the value of the velocity which satisfies the noise also dictates the fan design of the propulsion system. Scale-model augmentor-wing testing has shown that it is possible to reduce the noise of this powered lift system to acceptable values. Large-scale testing is required to insure that scaling will not invalidate the results.

It is concluded that viable propulsion system designs can be provided for the powered lift systems discussed. It was shown that the STOL noise goal and the 2000-foot field length have severe affects on the economics of the STOL system. Small variations in the noise goal and field length can yield large economic returns.

REFERENCES

1. C. C. Ciepluch, F. J. Montegani, M. J. Benzakein, and S. B. Kozin, "Quiet Engine Test Results," Aircraft Engine Noise Reduction, NASA SP-311, 1972, pp. 183-214.
2. F. B. Metzger and T. G. Ganger, "Results of Initial Prop-Fan Model Acoustic Testing," Hamilton Standard Rep. HSER-5787, NASA CR-111842, Dec. 4, 1970.
3. H. L. Wesoky and I. J. Loeffler, Unpublished test results, 1972.

4. F. Kuljber, "Results of an Experimental Program for the Development of Sonic Inlets for Turbofan Engines," AIAA Paper 73-222, Jan. 1973.
5. F. Klujber, J. C. Bosch, A. W. Demetrick, and W. L. Roff, "Investigation of Noise Suppression by Sonic Inlets for Turbofan Engines," NASA CR-121126, 1973.
6. B. A. Miller and J. M. Abbott, "Low Speed Wind Tunnel Investigation of the Aerodynamic and Acoustic Performance of a Translating Centerbody Choked Flow Inlet," proposed NASA Technical Memorandum.
7. B. A. Miller and J. M. Abbott, "Aerodynamic and Acoustic Performance of Two Choked-Flow Inlets Under Static Conditions," NASA TM X-2629, 1972.
8. T. W. Putnam and P. L. Lasagna, "Externally Blown Flap Impingement Noise," AIAA Paper 72-664, June 1972.
9. R. G. Dorsch and M. Reshotko, "Flap Noise Measurements for STOL Configurations Using External Upper Surface Blowing," NASA TM X-68167, 1972.
10. V. O. O'Keefe and G. S. Kelley, "Design Integration and Noise Studies for Jet STOL Aircraft," Boeing Co. Rep. D6-40552-1, NASA CR-114471, May 1972.

TABLE I. - FAN DESIGN CHARACTERISTICS

Parameter	QF-6		QF-9	
Overall total pressure ratio	1.20		1.20	
Rotor-stator separation, rotor chords	4.0		2.0	
Predicted overall efficiency, percent	87.9		90.2	
Corrected inlet weight flow, lbm/sec	873		889	
Corrected inlet specific weight flow, lbm/sec-ft ²	37.4		39.9	
	Rotor	Stator	Rotor	Stator
Number of blades	42	50	15	11
Chord, in.:				
Hub	6.89	4.61	8.46	15.0
Tip	6.40	4.61	13.5	15.0
Tip solidity	1.188	1.000	0.913	0.715
Rotor tip speed, ft/sec	750	-----	700	-----
Rotor inlet hub-tip radius ratio	0.416	-----	0.460	-----

TABLE II. - ENGINE COMPARISONS

	Blown flap		Current CTOL CF6-6
	GE19/F6E variable pitch	GE19/F2C fixed pitch	
Rated thrust	24 000	24 000	39 300
Fan pressure ratio - take-off	^a 1.25	^a 1.35	1.56
Fan tip diameter, in.	83	70	86.4
Corrected airflow	1200	969	1310
Turbine inlet temperature, °F	2440	2400	2370
Thrust/weight	5.7	6.7	5.2
M = 0.8, 30 K maximum cruise thrust	4900	5800	10 500
M = 0.8, 30 K maximum cruise SFC	0.76	0.695	0.635
Cruise thrust/weight	1.2	1.6	1.4
Cruise thrust/80 knots thrust	0.22	0.26	0.29
Fan pressure ratio - cruise	^a 1.33	^a 1.42	1.68
Bypass ratio - cruise	14.4	8.3	5.9
Overall pressure ratio - cruise	18.2	25	27

^a2-Position nozzle.

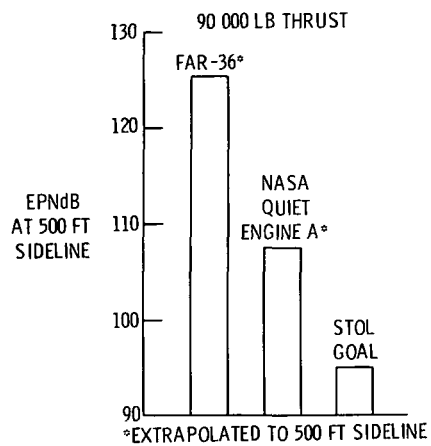


Figure 1. - Sideline noise comparisons.

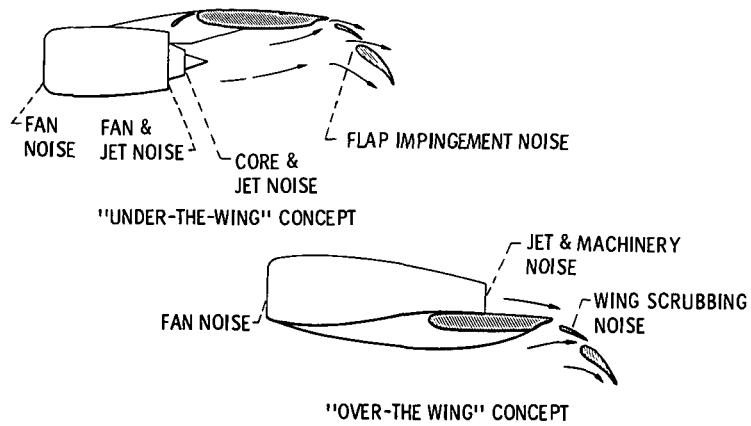


Figure 2. - Blown flap powered STOL system.

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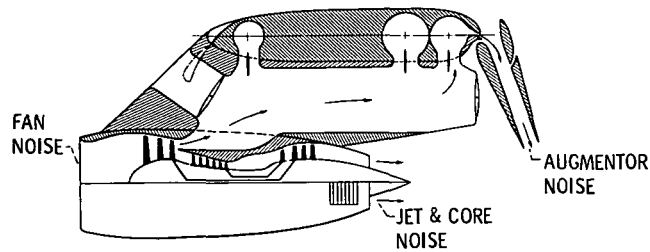


Figure 3. - Augmentor wing propulsion system.

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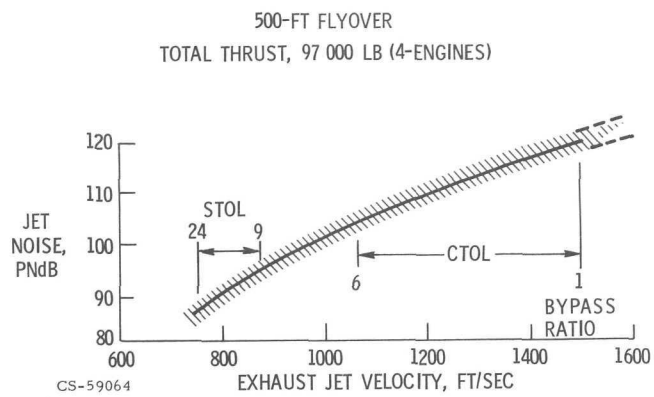


Figure 4. - Jet noise goal effect on propulsion design.



Figure 5. - Variable pitch, 6 ft diam. fan.

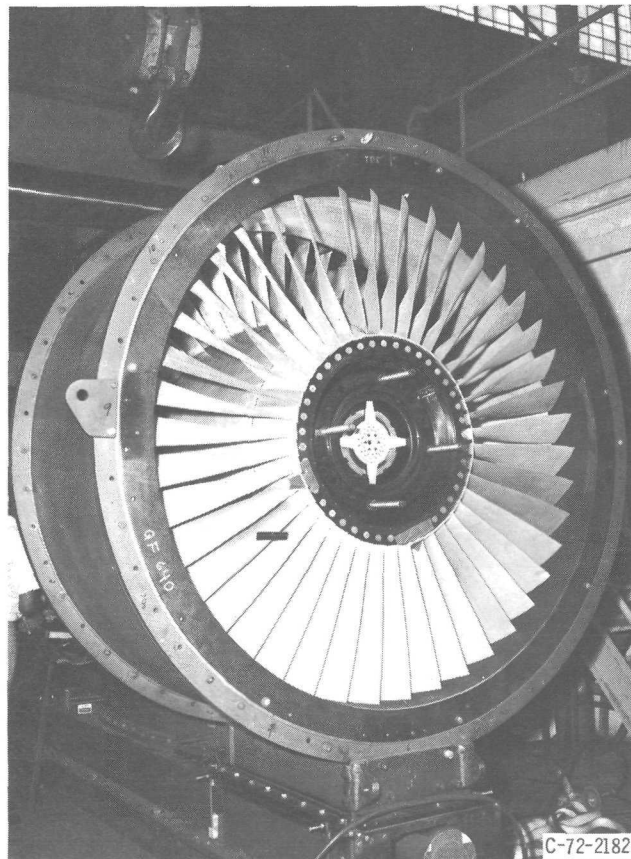


Figure 6. - QF6 fan - 1.20 pressure ratio.

100 FT RADIUS, 40° POSITION, 100% OF FAN DESIGN SPEED

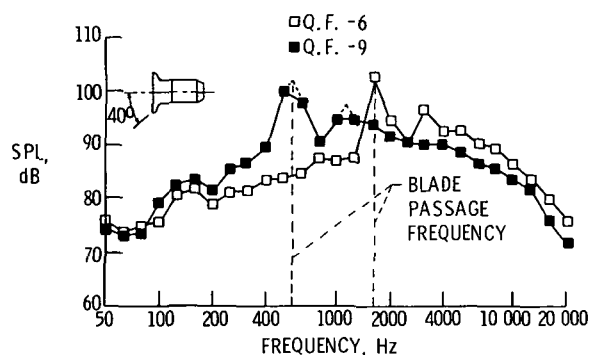


Figure 7. - Comparison of Q.F. -6 and Q.F. -9 fan 1/3 octave SPL spectra.

FOUR ENGINES - 90 000 LB TAKEOFF THRUST, 500 FT SIDELINE

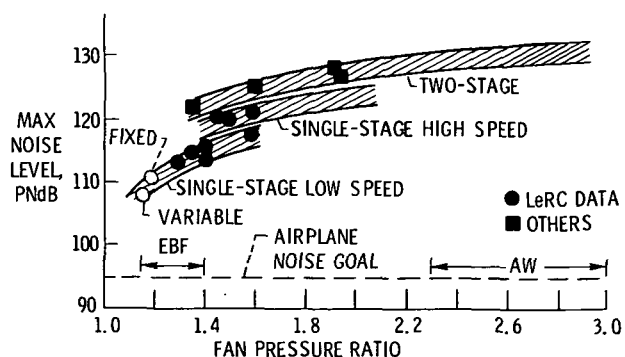


Figure 8. - Unsuppressed fan noise.

CS-64886

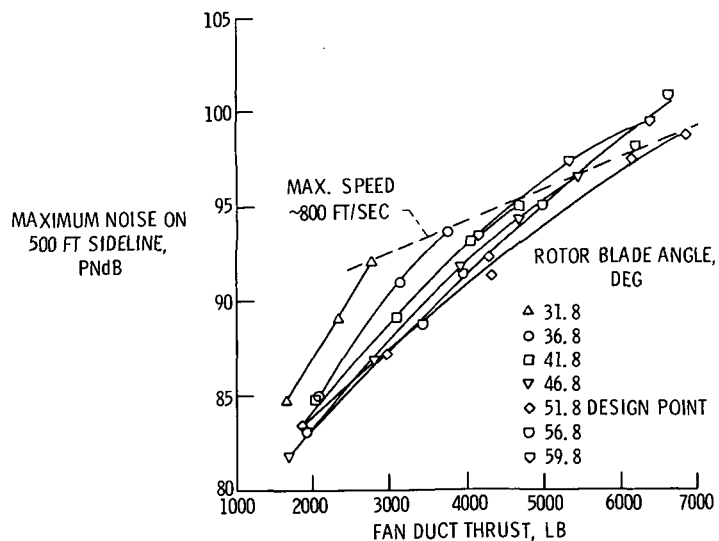


Figure 9. - Q-fan T-55 engine test data.

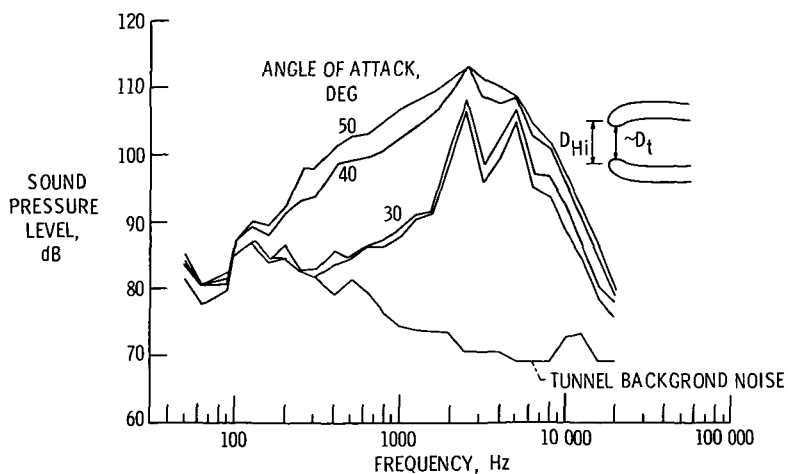


Figure 10. - Noise spectra at forward thrust for inlet with $A_1/A_t = 1.26$, tunnel vel. 86 kts.

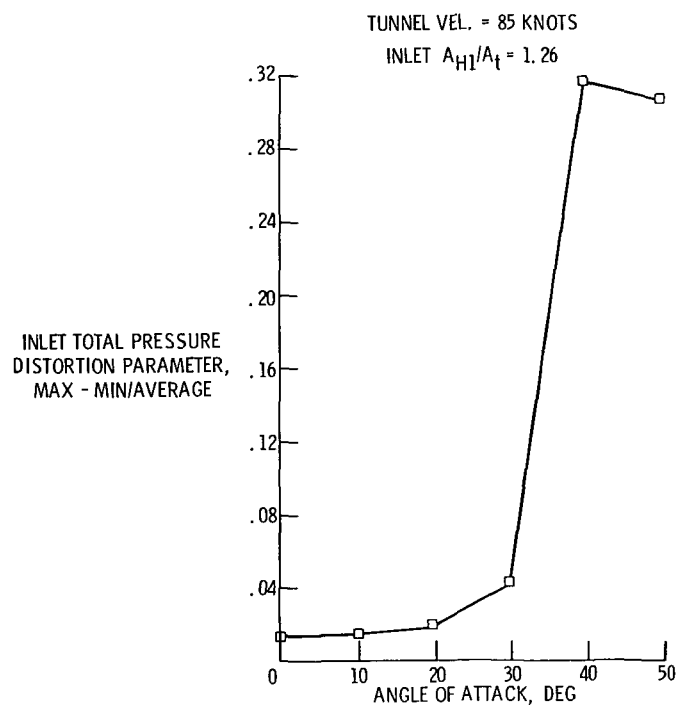


Figure 11. - Total pressure distortion.

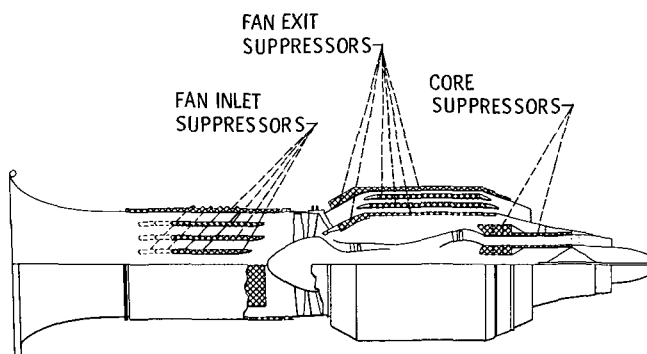


Figure 12. - TF34 fully treated nacelle separate flow.

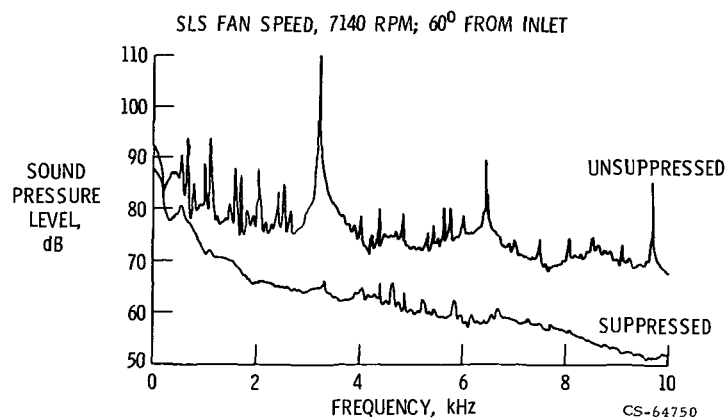


Figure 13. - TF-34 noise spectra at 100 ft.

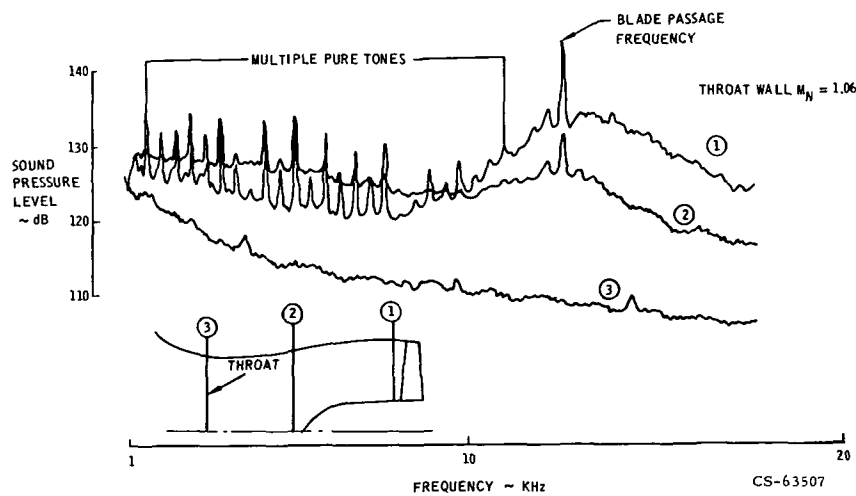


Figure 14. - Noise spectrum comparison behind a sonic inlet.

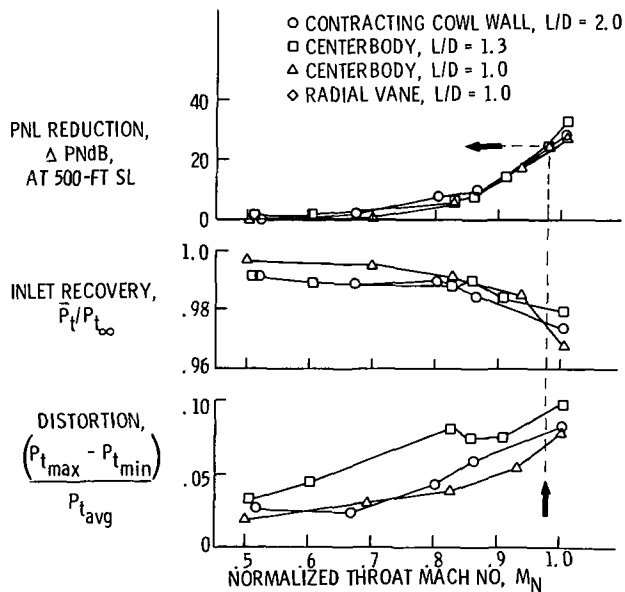


Figure 15. - Sonic-inlet performance-approach configuration.

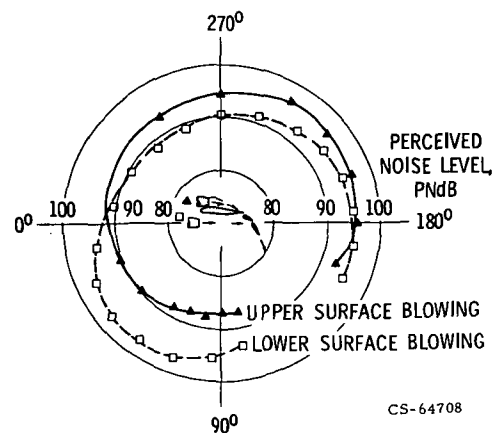


Figure 16. - Comparison of EBF perceived noise level patterns at 500 feet. Nozzle diameter, 13 in. Wing chord length, 7 feet. Flap position, 30°-60°. Exhaust velocity, 680 ft/sec.

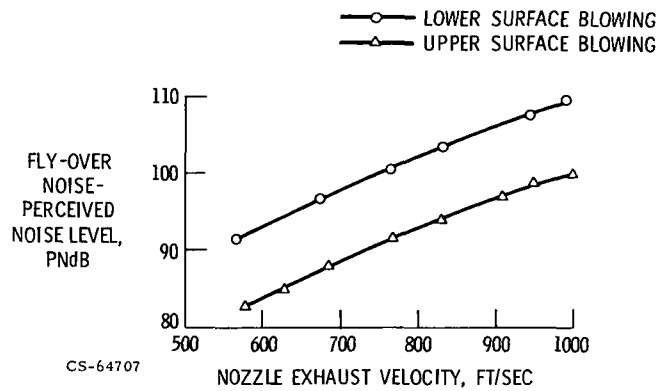


Figure 17. - Effect of nozzle exhaust velocity on EBF perceived noise level at 500 feet. Nozzle diameter, 13 in. Wing chord length, 7 feet. Flap position, 30°-60°.

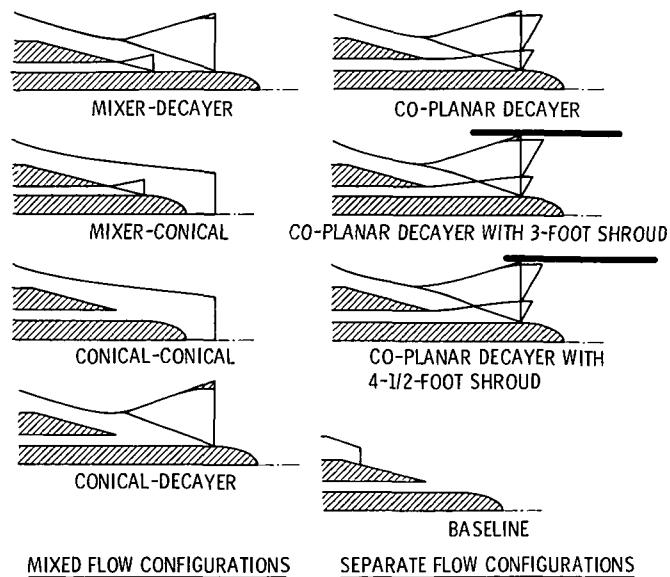


Figure 18. - TF-34 exhaust nozzle configurations.

SUPPRESSED ENGINE WITH WING AND FLAPS IN T. O. POSITION

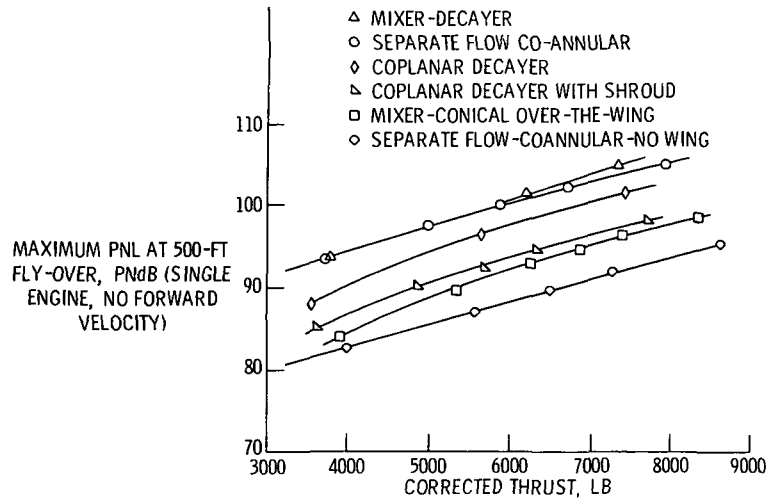


Figure 19. - TF-34 noise comparison.

TAKEOFF THRUST 500 FT SIDELINE 6235 SLS (WITHOUT EJECTOR) 6670 SLS (WITH EJECTOR)

- 0 - UNSUPPRESSED S-3A
- 1 - SUPPRESSED - SEPARATE FLOW
- 2 - SUPPRESSED - MIXER/DECAYER
- 3 - SUPPRESSED - CO-PLANAR/DECAYER
- 4 - SUPPRESSED - CO-PLANAR/DECAYER AND EJECTOR
- 5 - SUPPRESSED - MIXER/CONICAL - OTW

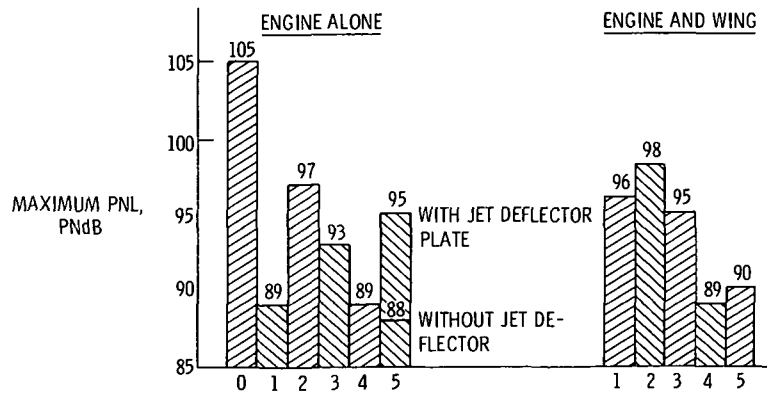


Figure 20. - TF-34 noise summary.

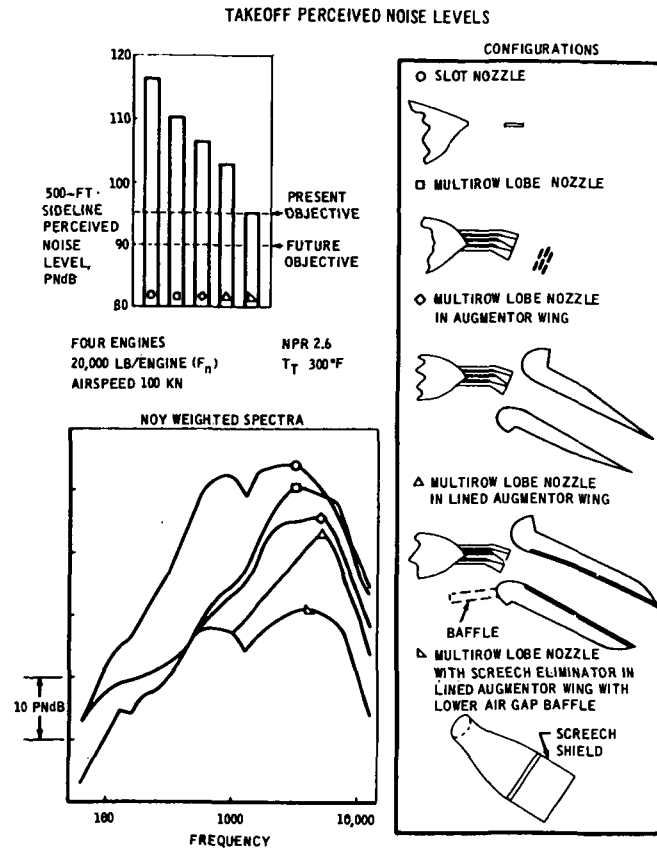
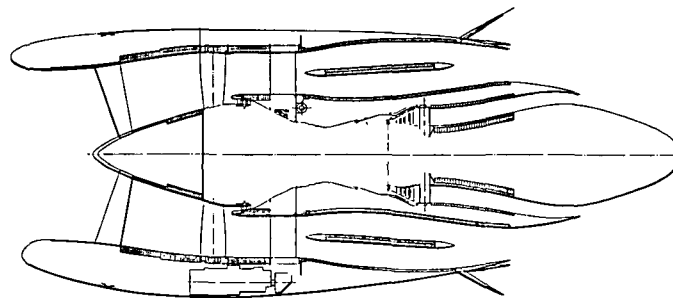
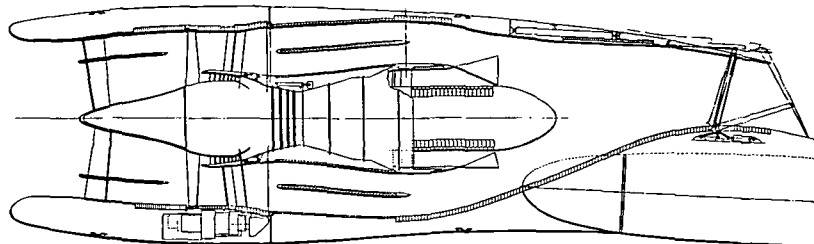


Figure 21. - Augmentor wing noise.

**VARIABLE PITCH ENGINE CYCLE CHARACTERISTICS**

UTW	GENERAL ELECTRIC	ALLISON
FAN PRESSURE RATIO	1.25	1.25
OVERALL PRESSURE RATIO	15.5	16.8
BYPASS RATIO	15.0	17.6
FAN DIAM, IN.	83	92.6
TURBINE INLET TEMP, °F	2 460	2 400
THRUST, LB	24 000	29 200

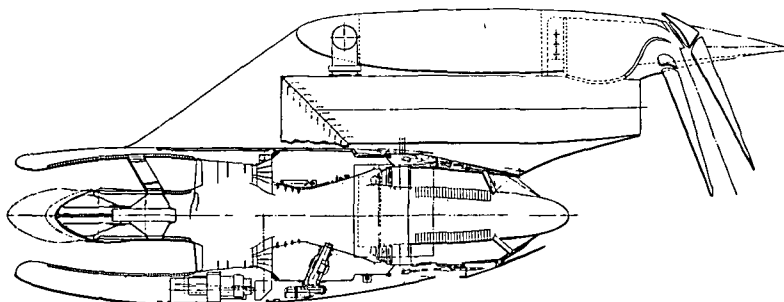
Figure 22. - Blown flap-under-the-wing variable pitch engine.



FIXED PITCH ENGINE CYCLE CHARACTERISTICS
OTW

	GENERAL ELECTRIC	ALLISON
FAN PRESSURE RATIO	1.35	1.35
OVERALL PRESSURE RATIO	22.7	20.0
BYPASS RATIO	8.3	12.8
FAN DIAM, IN.	70	84.4
TURBINE INLET TEMP, °F	2 400	2 400
THRUST, LB	24 000	28 800

Figure 23. - Blown flap-over-the-wing fixed pitch engine otw.



AUGMENTOR WING ENGINE CYCLE CHARACTERISTICS

	GENERAL ELECTRIC	ALLISON
FAN PRESSURE RATIO	3.0	3.0
OVERALL PRESSURE RATIO	24.9	21.8
BYPASS RATIO	2.2	2.5
FAN DIAM, IN.	45	45.75
TURBINE INLET TEMP, °F	2 370	2 300
THRUST, LB	14 000	14 560

Figure 24. - Augmentor wing engine variable inlet.

95 EPNdB AIRCRAFT
2000 FT FIELD LENGTH
125 PASSENGER AIRCRAFT

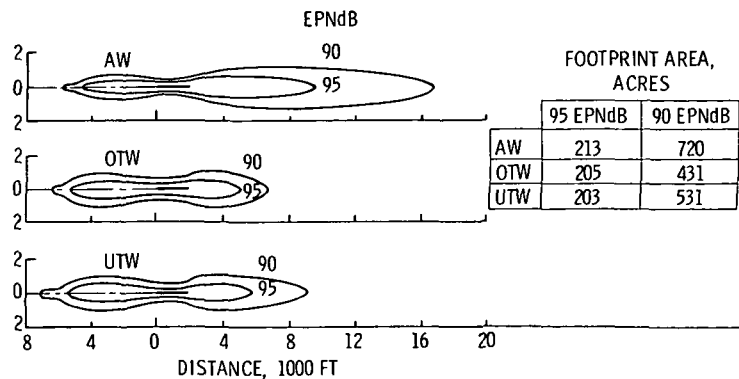


Figure 25. - Footprint comparison

2000' FIELD LENGTH
4 ENGINES (150 PASSENGER AIRCRAFT)
POWERED LIFT/30° FLAP
MAXIMUM ACOUSTIC SUPPRESSION

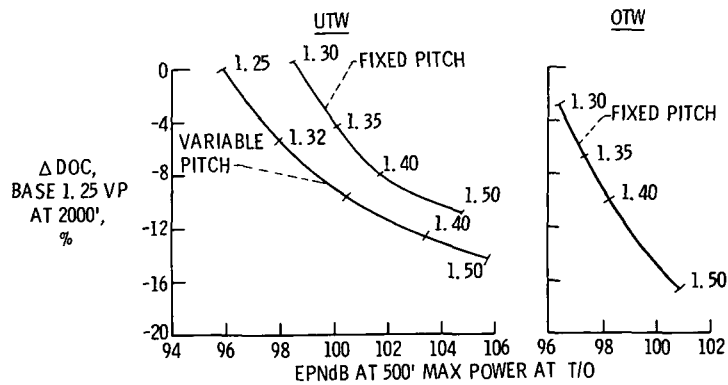


Figure 26. - Effect of noise on DOC.

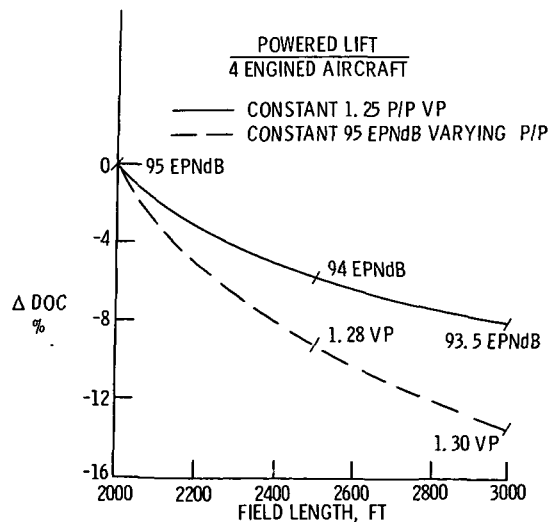


Figure 27. - Effect of field length on DOC.